Nepheloid Layer Measurements and Floc Model for OASIS

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LONG-TERM GOALS

The long-term goal of our research is to improve fundamental understanding and numerical representation of coastal bottom-boundary layer processes, with an emphasis on sediment dynamics. Our aim is to improve quantitative regional-scale models describing the relationships among meteorological and oceanographic forcing, freshwater influx, particle resuspension, and transport and accumulation of sediment in the coastal ocean. We are participating in the Optics Acoustics and Stress In Situ (OASIS) project to focus on the interaction between bed and suspended sediments and the influence of fine sediment and flocs on optical properties in the water column. Quantitative understanding of bottom-boundary layer processes and sediment dynamics is important to the Navy because these processes determine environmental conditions in coastal regions, including current speeds, turbulence, water-column turbidity, and bottom acoustic properties.

OBJECTIVES

The scientific objectives of our project are as follows:

- Measure detailed profiles of suspended sediment concentration and particle size in the bottom boundary layer (~bottom two meters), along with physical measurement of waves and currents, turbulence, and water properties.
- Use these measurements to constrain a simplified floc model to be implemented in a 3D, regional-scale numerical model for circulation and sediment transport (ROMS/CSTMS).

APPROACH

It is difficult to obtain vertical profiles of optical properties near the seafloor. The rapid attenuation of light in turbid water has frustrated the design of optical profiling instruments, and the differential fouling of optical surfaces compromises precise comparison among measurements made by instruments at different elevations. Additionally, some optical instruments are too large or too expensive to deploy in a vertical array. A specially modified tripod with a moving arm was designed to solve these problems by moving instruments vertically in the bottom boundary layer, between the bottom and about 2 meters above the sea floor.

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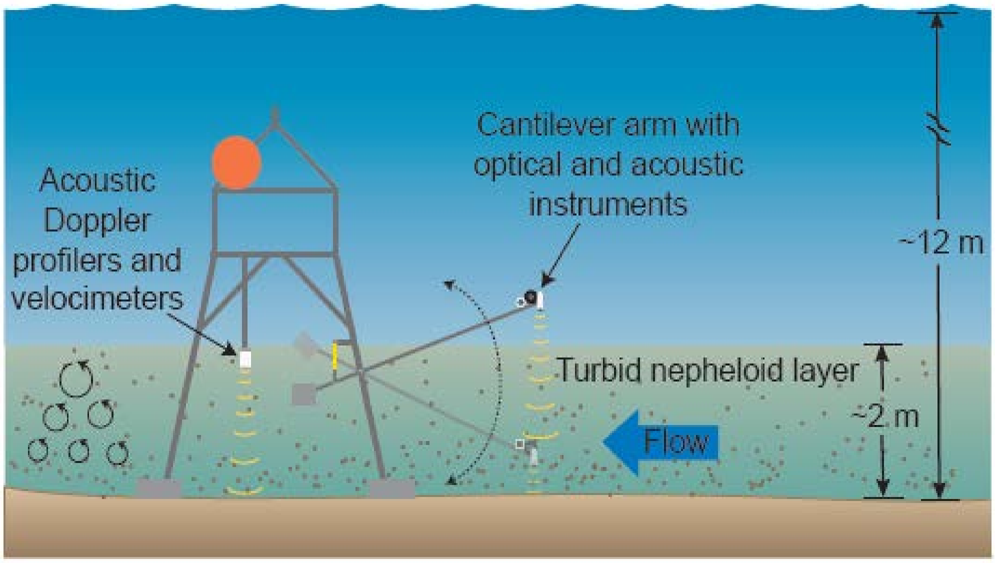

Figure 1. Conceptual illustration of the profiling tripod with instruments on a cantilever arm for profiling particle distributions in the bottom boundary layer. (Illustration by P. Dickhudt).

The vertical arm speed was chosen to move the instruments vertically fast enough that wave and current conditions could be considered stationary, but slowly enough to sample in approximately the same vertical location (within 10 cm) for several wave periods. Each profile took about 16 min at a speed of ~12 cm/min; four profiles (down, up, down, up) were made on 20-min intervals every two hours.

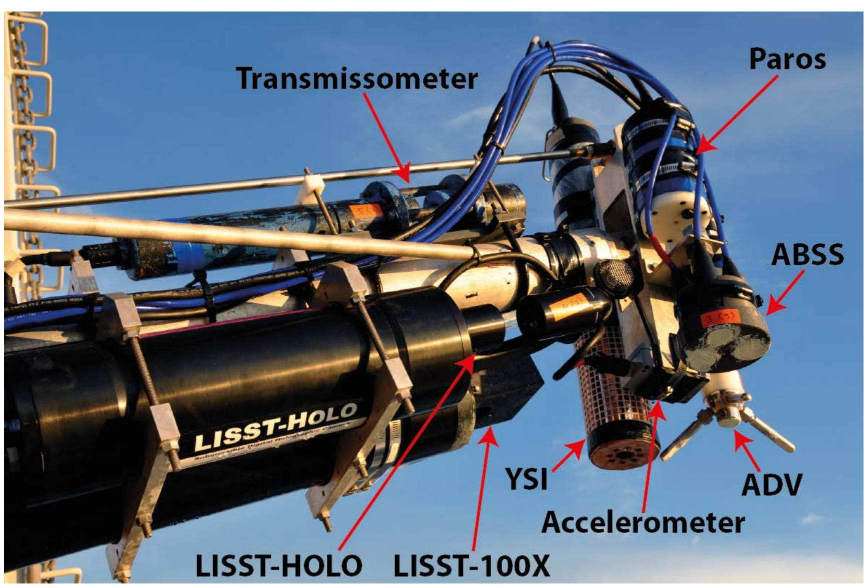

Figure 2. Photo of the profiling arm with instruments labeled. The vertical orientation of the instruments on the gimbaled package at the end of the arm (including the YSI, ABSS, and ADV) is maintained by the tie-rod assembly visible above the transmissometer.

WORK COMPLETED

The profiling arm was designed, built, and tested during spring and summer 2011 by the USGS. The tripod was connected to the Martha's Vineyard Coastal Observatory (MVCO), which provided power, the ability to monitor and control the arm movement, and the bandwidth to transfer to shore large datasets. Standard instruments (acoustic Doppler current meters, transmissometers, optical backscatter sensors, and conductivity / temperature sensors) were mounted on the tripod to measure waves, currents, Reynolds stress, vertical temperature and salinity gradients, and optical and acoustic proxies for suspended sediment. Several more instruments were mounted on the profiling arm, including a laser particle sizer (LISST 100-X), a prototype holographic particle imager (LISST-Holo), a transmissometer, three optical backscatter sensors, a three-frequency acoustic backscatter profiler, an acoustic Doppler velocimeter, a conductivity / temperature sensor, and an accelerometer. In addition, OASIS co-PI Boss deployed a WETLabs ac-9 that measured spectra of optical attenuation and absorption on both filtered and unfiltered water pumped from an intake on the end of the profiling arm.

The tripod and a small mooring for a profiling current meter were deployed from September 17 to October 23, 2011 at the MVCO 12-meter node. Exposed optical surfaces were cleaned weekly by divers. There was a range of wave and current conditions during the 36-day deployment, including the distant passage of Hurricane Ophelia, several moderate wave events, and a local gale that generated wave heights greater than 4 meters at the 12-meter site and knocked over the tripod 3 days before it was recovered. Until then, the profiling arm and all but one of the instruments functioned well and provided complete datasets.

The measurements reveal vertical gradients in optical properties that are relatively free of biases caused by fouling or instrument calibration. Profiles of acoustic backscatter were made from a constant range, removing some of the uncertainty associated with corrections for range-dependent attenuation. Remarkable observations of changes in size distribution with elevation were obtained with the LISST 100X, and the ac-9 provided extremely clean data that we have used to infer mass concentration profiles from beam attenuation (Boss et al., 2009; Hill et al., 2011) and particle sizes from gamma, the exponent relating particulate attenuation to wavelength (Boss et al., 2001).

All of the data from the profiling tripod has been processed, and has been documented and made publically available in a USGS Open-File Report (Sherwood et al., 2012).

We are using these data to evaluate various terms in the coupled mass conservation equations that relate changes in particle concentrations to horizontal advection, vertical diffusion, vertical settling, source terms like fluxes to (or from) the seafloor, and reaction terms that describe exchanges among size classes by aggregation and disaggregation.

RESULTS

Many of the results provide quantitative confirmation of expectations based on simple models. For example, estimates of particle settling velocity made for times when the mass balance is mostly between upward diffusion and downward settling (the Rouse equation) differ depending on the sensor properties and amount of turbulent resuspension. Acoustic backscatter intensity is proportional to total particle volume while optical sensors respond to total particle cross-sectional area. As a result, acoustic

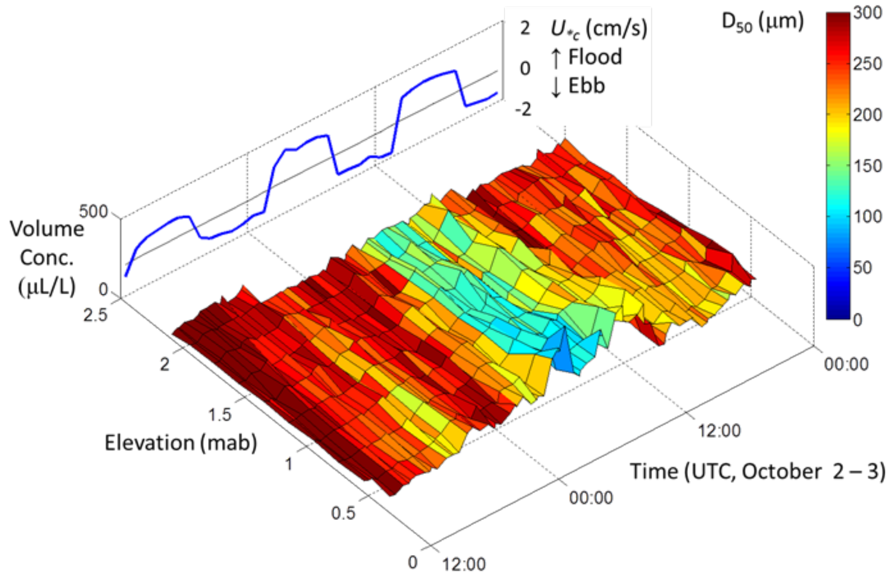

Figure 3. Perspective view of profiles from the LISST 100-X on the moving arm. Suspended particle volume concentration (z-axis, μL/L) as a function of elevation above the bottom (y-axis, meters), over 1.5 days in October (x-axis; hour:minutes), colored by the median particle size. The blue line on the back panel is measured current shear velocity u_{*c} (cm/s).

sensors are less sensitive to small particles. Our observations show that acoustic sensors predict stronger gradients in sediment concentration near the bed than optical sensors. This results in higher estimates of settling velocity when using the Rouse equation. Estimated settling velocities from both types of instruments increase during resuspension events, even as mean particle size measured by the LISST decreases, while total suspended mass is modulated by bottom shear stress. This indicates a shift in particle population from larger, lower-density flocs to smaller, higher-density particles.

We have also observed inverted particle-size profiles that we attribute to disaggregation of flocs by turbulent shear, and we measured highly uniform distributions of chlorophyll-rich particles modulated by bottom stress that suggest well-mixed resuspensions of diatoms.

IMPACT/APPLICATIONS

These measurements we are making will allow more critical evaluation for models of particle aggregation, acoustics, and optics than previously possible because the profiles are being made continuously with the same sensors and include co-located contemporaneous measurements of many key properties. This will lead to better and more complete models for flocs, sediment-transport, and diver visibility.

RELATED PROJECTS

None

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PUBLICATIONS

Sherwood, C.R., Dickhudt, P.J., Martini, M.A., Montgomery, E.T., and Boss, E.S., 2012, Profile measurements and data from the 2011 Optics, Acoustics, and Stress In Situ (OASIS) project at the Martha's Vineyard Coastal Observatory: U.S. Geological Survey Open-File Report 2012-1178, at http://pubs.usgs.gov/of/2012/1178/). [published]